Comments of the Consumer Electronics Association
MM Docket No. 99-325
January 24, 2000

APPENDIX A

FM Receiver Sensitivity to Host IBOC Digital Signals

Laboratory Test Report

November 9, 1999

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FM Receiver Sensitivity to Host IBOC Digital Signals
Laboratory Test Results

November 9, 1999

Objective

The purpose of these laboratory tests is to obtain a better understanding of the sensitivity of analog FM stereo receivers to the IBOC digital signal that causes an increase in the audio noise when tuned to the host FM signal. These tests were conducted on 14 consumer receivers that are a representative sample of the receivers used in this country. An additional top-of-the-line AM/FM tuner was part of the test sample. This receiver represented the ultimate in FM stereo signal detection (Receiver #6). The tests were conducted with new and old (5 years) receivers so that changes over time in receiver performance can be observed.

General

All three of the proposed IBOC digital radio systems transmit the digital signals in the first half of the upper and lower first adjacent channels to the host FM station. The signals are transmitted in two frequency bands that extend from 129 kHz to 198 kHz above and below the host FM channel center frequency. The IBOC proponents propose that the average power of the total IBOC signal be transmitted at a level approximately 22 dB lower than the host FM signal.

In 1995 EIA (CEMA) conducted digital audio radio tests with the objective of establishing a digital radio standard. These tests measured the digital performance and analog compatibility of three proposed IBOC systems. The shape of the digital RF waveform for one of the 1995 proposed IBOC systems (AT&T/Amati DSB system) is similar to the RF waveform proposed by the three new IBOC system proponents. A spectrum analyzer plot of the AT&T/Amati system is shown in Figure 1. The analog/digital average power ratio for these earlier tests was 15 dB. Because of the waveform similarity between the AT&T/Amati and the three new IBOC systems, the 1995 laboratory test data can be used as a benchmark for future system compatibility measurements and receiver evaluations.

There are many ways of decoding the FM stereo signal. In practice the PLL stereo decoder has become the norm. The PLL stereo decoder uses square wave switching to decode the 38 kHz stereo difference signal. This decoder is also sensitive to signals that are at the odd multiple of the 38 kHz. Without additional filtering or special 38 kHz decoders, the IBOC digital signals that occur at frequencies 114 kHz or 190 kHz above or below the FM channel center frequency will increase the stereo audio noise floor.

The 1995 CEMA (EIA) tests showed that interference to the host FM signal was receiver dependent. It was found that receivers that used the conventional PLL stereo decoders are sensitive to the IBOC digital signal. These unfiltered decoders are generally used in all FM stereo receivers with the exception of automobile radios.

Reduction in Digital Power Level

Since the 1995 tests the IBOC proponents have increased the power ratio between the FM and digital signals. For the 1995 tests the digital signal was 15 dB below the FM analog (-15 dBc). One of the IBOC proponents has proposed reducing the digital power by 7 dB. The digital signal power would be 22 dB below the FM analog (–22 dBc). This reduction in digital power will reduce the interference to the host FM signal on stereo receivers that are sensitive to these digital sidebands.

IBOC Signal Simulation

The purpose of this test is to simulate the IBOC digital signal at the 1995 power setting of –15 dBc and repeat the test at the recently proposed –22 dBc setting. RMS S/N measurements will be made on 15 consumer FM stereo receivers with these digital/analog power settings.

A block diagram of the simulation is shown in the Appendix, page 3 of 3. The host stereo signal is generated using a CRL stereo generator that modulates the RE110 RF signal generator. Modulating two FM signal generators (RE107) with clipped pink noise simulates the IBOC digital sidebands. The Simulated Digital SideBands (SDSB) center frequency was set at 163.5 kHz above and below the host FM center frequency. The waveform of the simulated IBOC sidebands signal is shown in Figure 1.

Simulation Calibration

The average power levels of the SDSB and analog signals were measured separately and then combined. The power was first set at -15 dBc for comparison with the 1995 compatibility test results. The column in Table 1, labeled AT&T/Amati lists the 1995 RMS S/N measurements made for the digital to host FM stereo tests. The third column shows the results of the S/N tests using the IBOC simulator. The fourth column lists the differences between the 1995 and 1999 compatibility tests. It is clear from the small differences between the 1995 tests and 1999 simulation that the effect of the interference caused by the simulation is comparable to the noise introduced by the AT&T/Amati system.

IBOC to Host FM S/N 1995 to 1999 Measurement Comparison Table 1			
Receiver	AT&T /Amati 1995 Tests RMS S/N –15 dBc	IBOC Simulation 1999 Tests RMS S/N –15 dBc	Difference
1. Delco auto	60.7 dB	61.0 dB	0.3 dB
2. Denon 380 HiFi	50.0 dB	50.0 dB	0.0 dB
3. Panasonic portable	44.2 dB	43.0 dB	1.3 dB
4. Pioneer HiFi	40.0 dB	39.5 dB	0.5 dB
5. Ford auto	64.0 dB	62.5 dB	1.5 dB

Receivers Used

Earlier this year (1999) FM receiver laboratory tests were conducted under the auspices of National Public Radio, Consumer Electronic Manufacturers Association, and Corporation for Public Broadcasting. The results of these tests are contained in a report filed with the FCC and titled FM Receiver Interference Tests, Laboratory Test Report. The FM interference tests were conducted using the 16 consumer FM stereo receivers. Each of the receivers was thoroughly characterized and the results are part of the laboratory test report. Fifteen of the receivers used for FM tests were used for the IBOC simulation tests.

IBOC Digital to Host Analog Tests

Table 2, Chart 1, and the data on page 2 of 3 in the appendix show the results of the simulation tests.

The tests were conducted with the simulated digital sidebands' power level set at -15 dBc and –22 dBc below the analog FM signal. The tests were conducted with a –47 dBm desired RF signal level. The audio S/N measurements were RMS unweighted.

Chart #1 shows the results of three RMS S/N measurements on the 15 receivers. The square blocks represent the S/N without the IBOC digital signal added. The diamond represents the S/N for each receiver with the original IBOC digital signal insertion level 15 dB lower than the FM (-15 dBc). The circle is the receiver S/N with the digital signal set at –22 dBc. It is clear from the graph that the level of interference is receiver dependent.

Receivers 1, 5, and 15 are OEM auto radios and are not adversely affected by the digital signal. Receivers 7 and 13 are aftermarket auto radios, and the S/N is reduced by the digital signal.

Table 2 shows the results of the tests and includes receiver estimated age, receiver type, and manufacturer model number.

Table 2. Consumer FM Receiver Test Results						
Number	Make and Model	Type	Age in Years	RMS S/N at -15 dBc	RMS S/N at –22 dBc	RMS S/N no Digital Signal 1999 Test
1	Delco Model: 16192463	Auto OEM	5	61.0 dB	61.0 dB	60.5 dB
2	Denon Model: TU-380RD	Home HiFi RDS	5	50.0 dB	57.0 dB	69.0 dB
3	Panasonic Model: RX-FS430	Portable	5	43.0 dB	50.0 dB	66.0 dB
4	Pioneer Model: SX-201	Home HiFi	5	39.5 dB	46.5 dB	67.5 dB
5	Ford Model: F4XF-19B132-CB	Auto OEM	5	62.5 dB	65.0 dB	66.0 dB
6	Denon Model: TU-680NAB	Home HiFi high end	4	66.0 dB	70.0 dB	70.0 dB
7	Audiovox Model: AV-220	Auto aftermarket	5	53.0 dB	57.0 dB	60.0 dB
8	Sony Model: STR-AV21	Home HiFi	8	46.5 dB	53.0 dB	67.0 dB
9	Sony Walkman Model: SRF-M40W	Personal portable	9	47.0 dB	53.5 dB	62.0 dB
10	Technics Model: SA-EX110	Home HiFi	1	50.0 dB	57.0 dB	66.0 dB
11	Sanyo Model: MCS736	Shelf combo	1	38.5 dB	45.0 dB	60.5 dB
12	Sony Model: CFD-S33	Table combo	1	39.5 dB	46.0 dB	61.5 dB
13	Koss Model: MS-457	Auto aftermarket	1	49.0 dB	55.0 dB	64.5 dB
14	Phillips/Magnavox Model: AZ2700/17	Portable	1	47.0 dB	53.0 dB	61.0 dB
15	Ford Model: XF3F	Auto OEM	1	58.0 dB	58.0 dB	58.0 dB

Effect of Reduced Digital Power

The number of receivers that had audio S/N ratios of 50 dB or lower varied significantly with the digital signals set at –15 dBc and –22 dBc. With the digital power set at –15 dBc ten of the receivers' S/N measured 50 dB or lower, and with –22 dBc four receivers' audio S/N was 50 dB or lower.

New Versus Older Receivers (Home and portable types only)

Five new and six of the older receivers were used for this analysis. Receiver #6, the Denon TU-680, was not used. The TU-680 is the ultimate in AM and FM tuner design and because of its high cost had a very low market penetration. The average RMS audio S/N for the four new receivers was 44 dB at –15 dBc and 50 dB at –22 dBc. The average

S/N for the five older receivers tested is 45.2 dB at –15 dBc and 52 dB at –22 dBc. The older receivers used for this analysis are receivers number 2, 3, 4, 8, and 10. The new receivers are number 10, 11, 12, and 14. The older receivers were 1.2 dB quieter at –15 dBc and 2 dB quieter at –22 dBc.

Conclusions

1. The reduction in digital power by 7 dB improved the average receiver audio S/N performance by almost 7 dB.

2. The stereo noise floor increase caused by the IBOC digital signal on the received host FM signal was essentially the same for the new and older receiver groups.

3. The tests were conducted at a strong –47 dBm signal level where analog FM interference should be low.

4. When tuned to the IBOC host station the three OEM auto radios' audio S/N is not degraded with the presence of the digital signal at either insertion level.

5. The two after market auto radios' S/N was reduced with the presence of the digital signal at both signal levels.

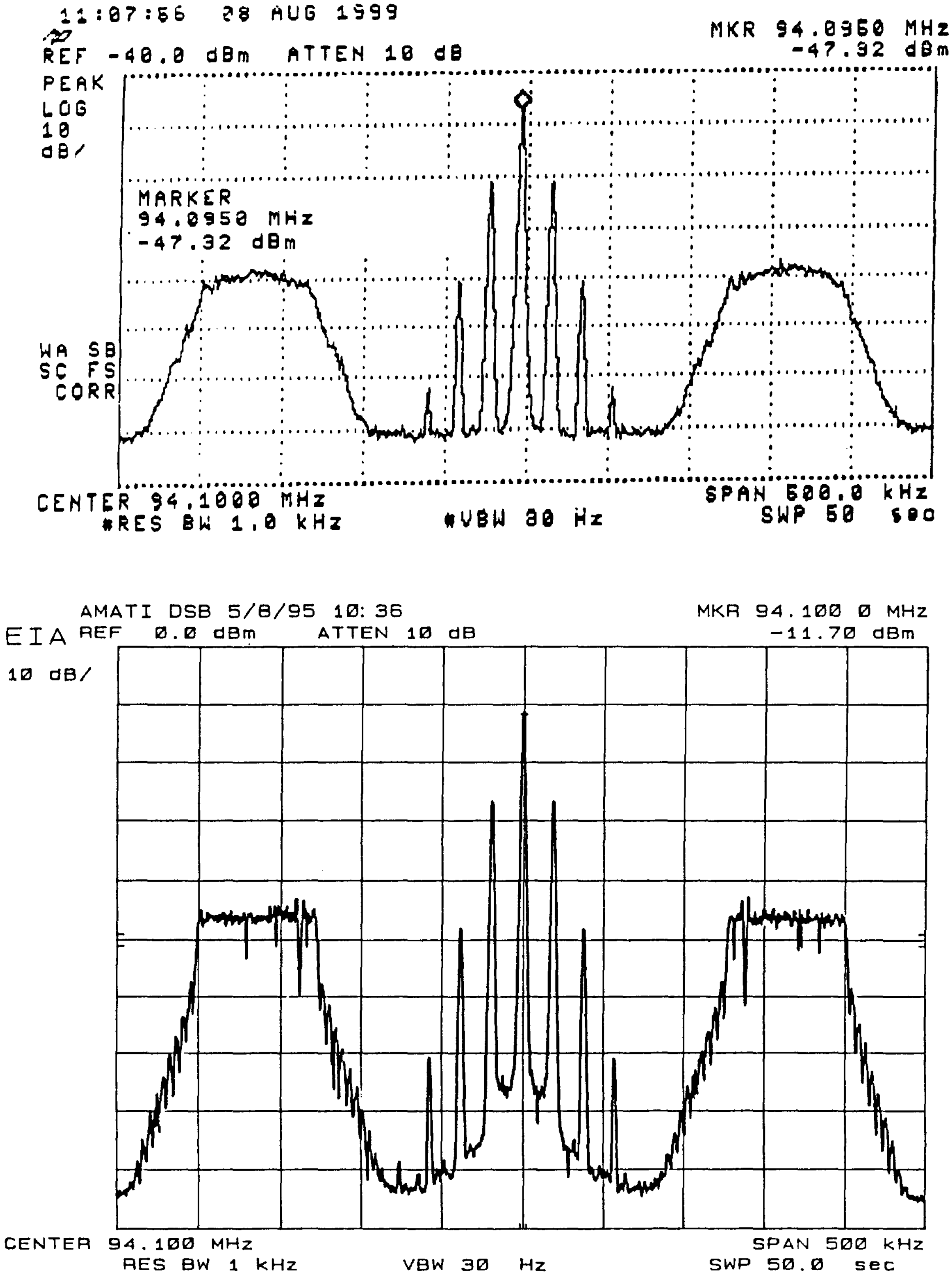
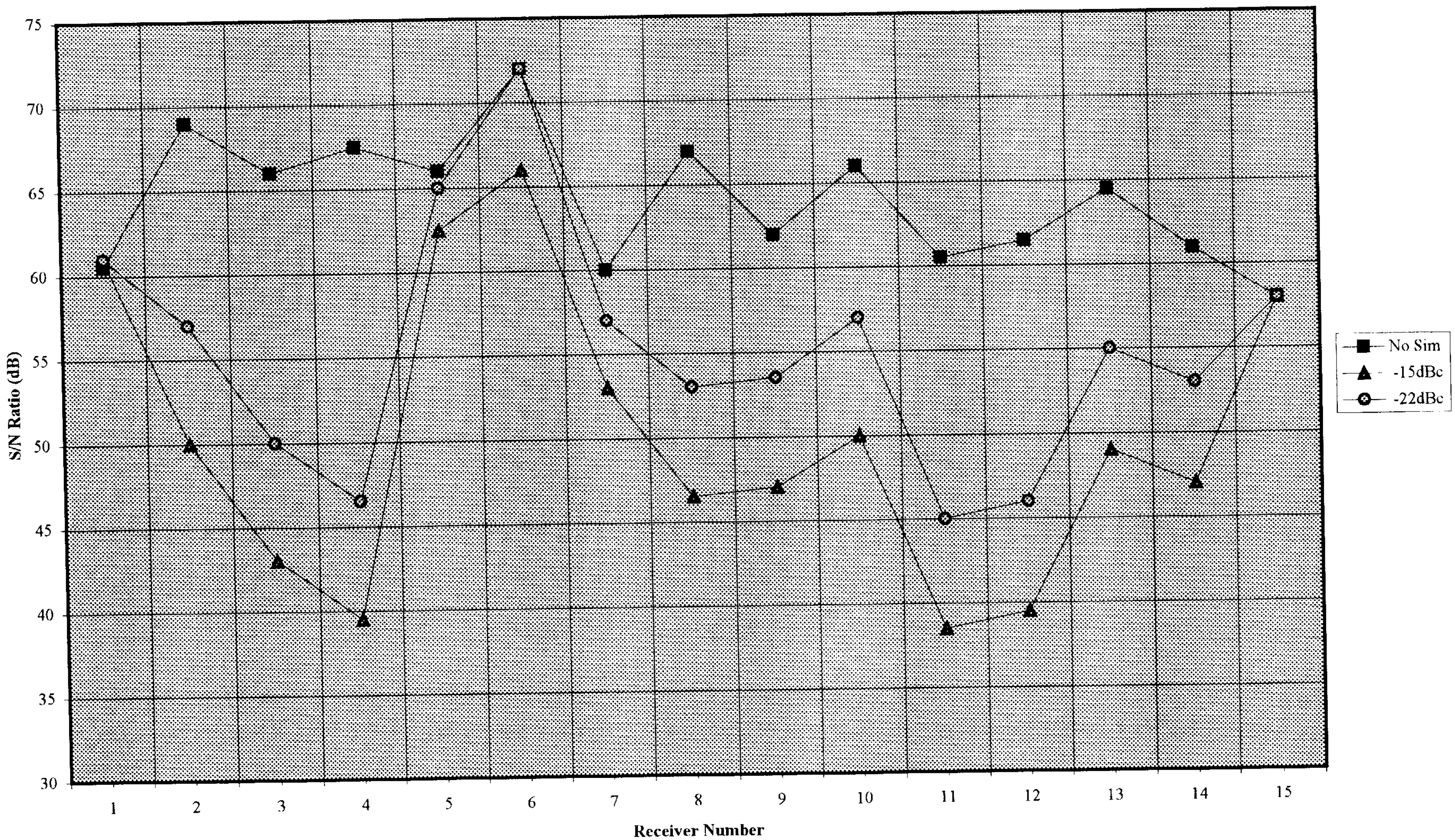


Figure 1.

Spectrum Analyzer Plots

Upper plot IBOC simulation August 1999 – Lower plot Amati IBOC system 1995

Chart #1
Signal to Noise Ratio vs. Receivers
With DAB Sim Levels at -15dBc and -22dBc



APPENDIX

FM Receiver Test Laboratory

Date: 8/5/99
Engineer: RMc
Test Series: H DAB Simulation
Description: DAB simulation set up 1
Reference AMATI signal

Saddlebag Peaks: 114kHz + 15kHz
Inside peak: 129 kHz
Outside peak: 198 kHz
Center f: 163.5 kHz

Desired f: 94.100 MHz
Upper Sim f: 94.264 MHz
Lower Sim f: 93.937 MHz

Sim Modulation: Pink Noise into Orban Stereo Proc. into RE107 upper and lower.
Orban set for heavy proccesing (-15dB front panel reading), with Pilot OFF
Orban output into Ext. 4 of each RE107 RF generator
RE107 front panel modulation setting 60kHz (uncal - only an attenuator setting)
AFM2 Modulation Meter reading 43kHz (wideband setting)

Sim Levels: Using CW all three signals are calibrated for 45dBm (0dB D/U)
The Output Attenuator is set to 2dB for -47dBm (Desired operating level)
The Undesired attenuator is set to 70dB for -15dBc

Alternate Levels: Undesired attenuator set to 77dB for -22dBc

Set up 2: Same as above only less modulation on the Undesired signals
RE107 front panel setting; 55kHz
AFM2 Modulation Meter reading; 38kHz (wideband setting)
This is the final modulation level after fine tuning the DAB Sim

Plots: Spectrum Analyzer settings:
Center f: 94.1MHz
Span: 500kHz
Atten: -40dBm
RBW: 1kHz
VBW: 30Hz
Sweep: 50.0sec

FM Receiver Test Laboratory

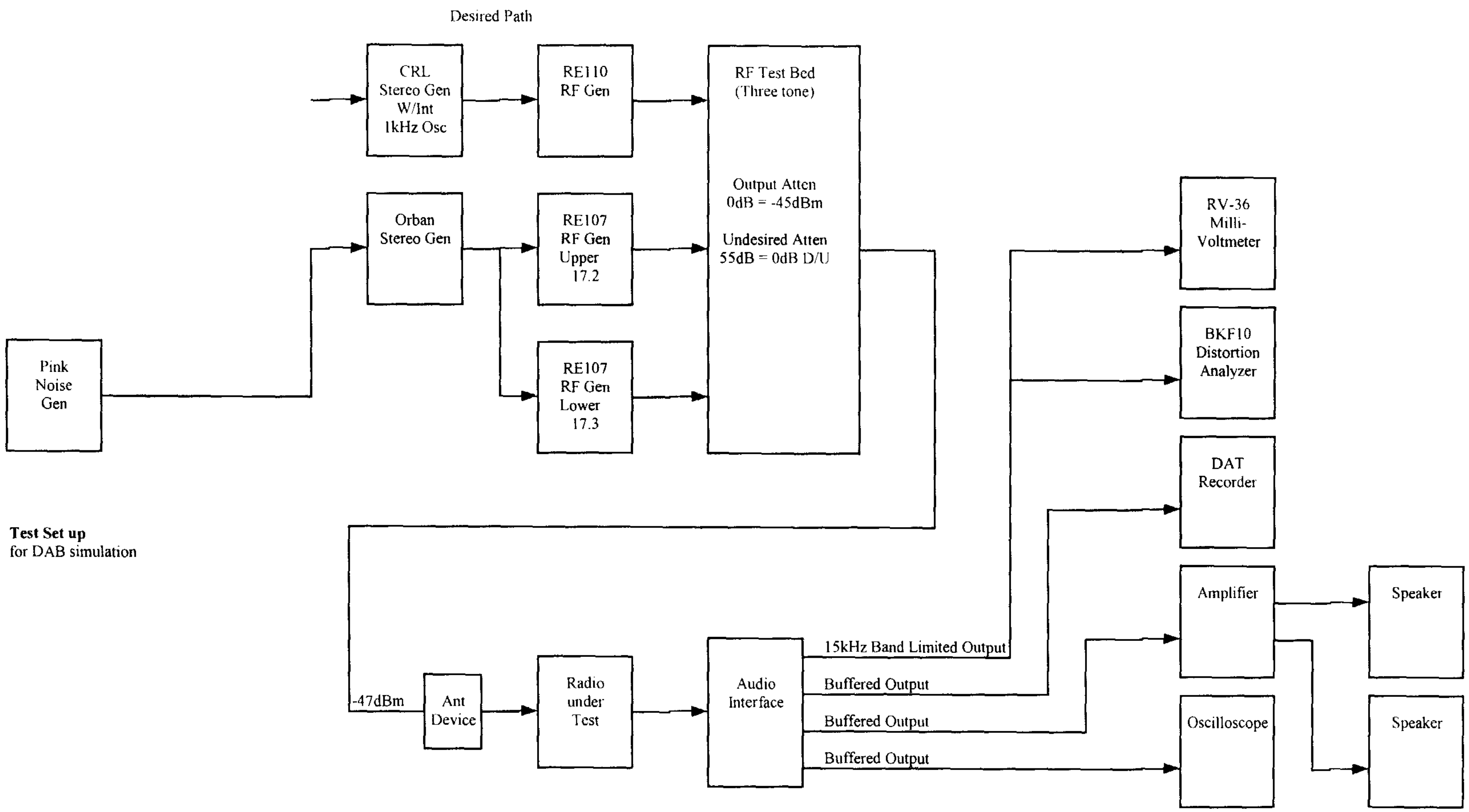
Power Measurements: In addition to plotting the signal, power measurements were made as well using the Boontom power meter.
Correlation & Linearity) Increasing the DAB Sim signal with the Undesired attenuator put the DAB Sim signal within the range of the power meter. The desired level for these measurements was -45dBm, with the Desired signal off.
Upper and Lower DAB Sim carriers were measured individually as well for correlation to Spectrum Analyzer measurements
(Desired carrier is present only in Plots as a reference)

D/U rel -45dB	Pwr Meter W/Mod.	WO/Mod	Low. Onl O/Mod	Up. Only O/Mod.
+20dB	-22.2	-22.2	-25.25	-25.3
+40dB	-2.01	-2.01	-4.97	-5.02

Receiver Measurements

Referen	Best S/N (Stereo)	RMS QPK	60.5	69.0	66.8	67.5	66.0	68.5	59.2	68.0	59.5	65.5	60.5	60.50	63.6	61.2	57.5
	→		A	B	C	D	E	F	G	H	I	J	K	L	M	N	P
		Receiver No.	Delco 1	Den380 2	Pana 3	Pioneer 4	Ford 5	Den680 6	Audivox 7	SonyHF 8	onyW 9	TechHF 10	Sanyo 11	SonyTR 12	Koss 13	Magna 14	Ford 15
Desired Only		S/N	60.5	69.0	66.0		66.0	>70	60.0	67.0	62.0	66.0	60.5	61.5	64.5	61.0	58.0
DAB Set up 1	-15dBc	S/N		48.0													
DAB Set up 1	-22dBc	S/N		55.0													
DAB Set up 2	-15dBc	S/N	61.0	50.0	43.0		62.5	66.0	53.0	46.5	47.0	50.0	38.5	39.5	49.0	47.0	58.0
DAB Set up 2	-22dBc	S/N	61.0	57.0	50.0		65.0	>70	57.0	53.0	53.5	57.0	45.0	46.0	55.0	53.0	58.0

FM Receiver Test Laboratory



Test Set up
for DAB simulation

FM Receiver Test Laboratory

Receiver Group

No.	Mfg / Model	No.	Mfg / Model	No.	Mfg / Model
1	Delco Automobile Model: 16192463 Serial: 1000499	7	Audiovox Automobile Model: AV-220 Serial: 30901807N	13	Koss Automobile Model: MS-457 Serial: 3805003200
2	Denon Home Hi Fi Model: TU-380RD Serial: 4056301149	8	Sony Home Hi Fi Model: STR-AV21 Serial: 802086	14	Phillips/Magnavox Model: AZ2700/17 Serial: KT019841120616
3	Panasonic Portable Model: RX-FS430 Serial: GR3JA01184	9	Sony Walkman Model: SRF-M40W Serial: 194352	15	Ford Auto Radio (new) Model: XF3F-18C870-BF Serial: WANM000067
4	Pioneer Home Hi Fi Model: SX-201 Serial: OA3965843C	10	Technics Home Hi Fi Model: SA-EX110 Serial: GY8JA38798		
5	Ford Automobile Model: F4XF-19B132-CB Serial: 9411	11	Sanyo Shelf Combo Model: MCD-S736 Serial: 8701316		
6	Denon Home Hi Fi (NAB) Model: TU0680NAB Serial: 2092400103	12	Sony Table Model: CFD-S33 Serial: 1132161		

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APPENDIX B

Concept design for a
Mobile Multimedia Broadcast Service (MMBS)

Prepared under contract for the Consumer Electronics Association

September 13, 1999

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Concept design for a Mobile Multimedia Broadcast Service (MMBS)

Prepared under contract for the
Consumer Electronic Manufacturers Association
(CEMA)

September 13, 1999

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Executive summary

This report reviews the challenges of a mobile reception environment for a digital broadcast service primarily directed to car reception. It proposes a system concept for a Mobile Multimedia Broadcast Service (MMBS) for operation in the UHF band.

Mobile reception is faced with a very fundamental constraint. The propagation of the emitted signal dictates the maximum distance that can be covered from the transmitter. The distance is determined primarily by the transmit antenna height and by the transmit power. Reception is intrinsically limited by the presence of thermal noise in the receiver front-end and environment noise captured by the antenna. This determines the minimum signal field strength that is required to provide proper reception in an otherwise perfect channel. Reception is also impacted by the presence of signal echoes due to multipath, creating signal spreading in the time domain. For digital systems, these echoes tend to produce inter-symbol interference, which results in unreliable reception even in areas where the level of the received signal would normally be sufficient. In the case of mobile reception, this situation becomes even worse with these echoes being modulated by the motion of the receiver, creating signal spreading in the frequency domain. It is well known, in the world of mobile radio telephony, that this is as a very difficult channel environment. In the case of MMBS, however, some advantages can be taken from the fact that the prime service is unidirectional.

A number of modulation formats were reviewed and it was found that an approach using multi-carrier modulation, has clear advantages for the reliable reception of multichannel sound and data services in the UHF band. The advantages of this modulation technique are that inter-symbol interference can be reduced greatly by stretching the transmitted symbols, while maintaining the data throughput, by modulating a large number of carriers within the transmission channel. In order to preserve spectrum, these carriers are spaced as close as possible and are kept orthogonal to each other in order to minimize mutual interaction. This is done quite systematically by the use of an inverse FFT at the transmitter and an FFT at the receiver, with the spacing of the carriers set to the inverse of the symbol length. This arrangement of multiple carriers has the virtue of allowing the inclusion of a guard interval, between each transmitted symbol, in such a way that the inter-symbol interference is completely removed at the cost of a fraction of a dB in receiver sensitivity and a small fraction of the channel throughput. Finally, the use of time and frequency interleaving, in combination with convolutional channel coding and Viterbi soft decoding at the receiver, allows successful recovery of the signal, even when many of the carriers are affected by fading. These special features such as orthogonal carriers, guard interval and time/frequency interleaving with channel coding constitute the key features of the "Coded Orthogonal Frequency Division Multiplex" (COFDM) modulation, used and proposed for a number of digital broadcast and other radio systems aimed at mobile reception.

A particular characteristic of the mobile channel is the presence of flat fading over a relatively wide bandwidth, due to the presence of very close-in echoes. It was found, through field measurements, that a sizable improvement in reception reliability can be achieved if the transmission bandwidth can be increased to about 2 MHz. Beyond this point, one sees diminishing returns in increasing the bandwidth further. Accordingly, a channel bandwidth of 1.5 MHz, which is close to the requirement and can fit four times in a 6 MHz-wide channel, seems to be a good choice for an MMBS channel.

Another key characteristic of the mobile channel is its time variability as a function of speed of the vehicle. It was found, through extensive laboratory and field testing, that in order to preserve the performance of the transmission for vehicle speeds up to 120 km/h, the useful symbol period over which the signal has to be integrated needs to be limited to about 500 μsec in the case of a simple

differential QPSK demodulation at 770 MHz. Longer symbol periods would result in increasing sensitivity of the system to the channel Doppler spread created by moving vehicles. This is linked to the fact that the guard interval separating the useful symbols needs to be maximized for the reasons presented below, yet still represent a small fraction of the useful symbol in order to maintain a reasonable system throughput.

Although, in practice, most of the multipath energy coming from the surrounding falls within an excess delay of 30 μsec, the guard interval needs to be the longest possible to accommodate and facilitate the implementation of on-channel repeaters. These repeaters allow for the progressive build up of very reliable service coverage, over specific areas at much lower total transmit power than in the case of a single transmitter. Flexibility in locating these on-channel repeaters is improved with a longer guard interval. There is an intrinsic limit to the size of this guard interval related to the channel Doppler spread limitation and the system capacity. The normal practice is to set aside some 20% of the total symbol length as a guard interval and 80% for the useful symbol period. For the 500 μsec period set above for the useful symbol, this results in a guard interval of 125 μsec, corresponding to a maximum repeater spacing of 50 km to develop a synchronized Single Frequency Network. This distance drops to 25 km for implementation of on-channel repeaters using the signal received off-air from a main transmitter.

In order to keep the receiver as simple as possible, DQPSK is used as basic modulation so that the receiver does not have to predict and track the complex behavior of the mobile multipath channel. A relatively simple synchronization mechanism is needed to simply keep the receiver integrating the signal during the useful symbol period and discard the guard interval during which most of the potential inter-symbol interference falls. In the case of other modulations, a full knowledge of the channel state is needed in terms of the amplitude, phase and excess delay of each echo arriving at the receiver. The tracking of this complex time varying channel becomes rapidly horrendous when the vehicle moves at high speed.

With the fundamental findings about the behavior of the transmission channel at 770 MHz, a MMBS strawman system was developed. Its key features are: 768 orthogonal carriers separated by 2 kHz transmitted in a 1.5 MHz band, each carrier is modulated by differential QPSK, a guard interval of 125 μsec is set aside to separate the 500 μsec useful symbols to eliminate inter-symbol interference and allow on-channel repeaters with up to 50 km separation. Forward error correction is provided through the use of a Reed-Solomon code concatenated with a convolutional inner code of rate ½ along with appropriate time and frequency interleaving. The resulting system spectrum efficiency is 0.75 bit/s/Hz which results in a system throughput of 1.125 Mbit/s including the overhead for the Reed-Solomon code.

Assuming that a multichannel audio program can be encoded in 288 kbit/s and that an ancillary data channel of 64 kbit/s is to be included, this results is a 375 kbit/s bit stream when the FEC block coding overhead is added. This means that each 1.5 MHz channel can carry three multichannel audio./data programs. Assuming that six 6 MHz UHF channels are used for MMBS, this results in 6 x 4 = 24 MMBS channels each one carrying 1.125 Mbit/sec or three multichannel audio/data programs for a total of 72 multichannel audio/data programs in the entire band.

However, this entire capacity is not all available in a given area. There is a need to allocate the use of these channels among neighboring markets in order to limit the extent of co-channel interference. The UHF DTV plan was used as a reference for a simple exercise to assess the potential capacity in MMBS channels that each city could have. It was found that if networks of on-channel transmitters are used to more tightly control the signal drop-off at the edge of the service areas, although the service availability for the MMBS is to be higher than that of DTV (i.e., F(90,90)), it is possible to work on the assumption that the range of coverage area separation distances used in the DTV plan (i.e., 36-64 km) can also be used for MMBS. This would result in the same frequency repetition number and since the total number of MMBS channel (24) is half of that available to DTV (49), the typical MMBS capacity per city would be half, ranging from 4 to 9 channels in the largest US cities.

Co-location of transmit facilities, in a given coverage area would allow for a better spectrum use avoiding large signal differential which would result in adjacent channel interference and receiver RF-front-end non-linear behavior. This is even more important in the case of the use of on-channel repeaters because the instances of such large signal differentials would occur in many more places.

Obviously, some variation in the suggested strawman parameter values is possible, and there is room for optimization in the system parameters to improve the situation. This is beyond the scope of this report and would be left to the actual detailed system design. However, it is unlikely that the overall capacity values will vary greatly from those found in this study, unless a totally different trade-off is used among the spectrum capacity, the power requirement and the flexibility in using and locating the on-channel repeaters.